IEEE 802.16 Wireless Metropolitan Area Network (wMAN)

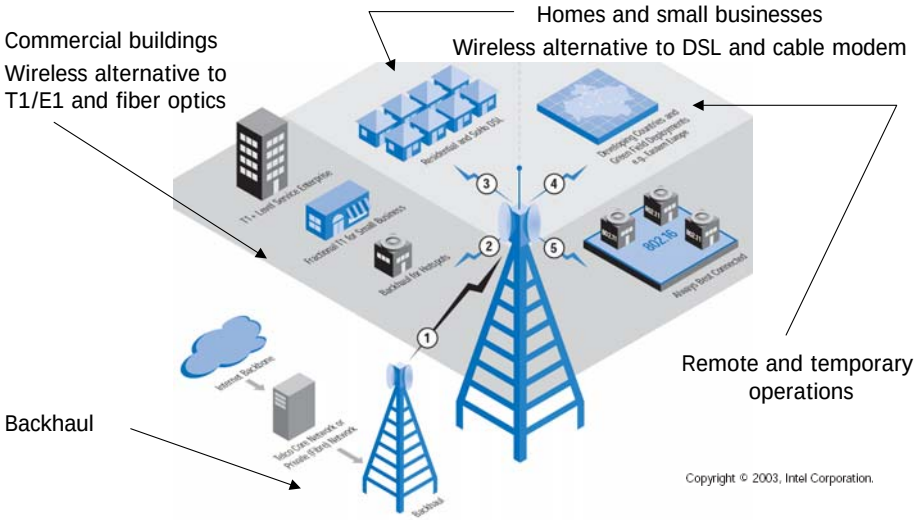
Existing Data Network Hierarchy

Level	Typical Connections	Wired Technologies	Wireless Technologies
Personal Area (PAN)	Peripherals and personal accessories	Serial / parallel cables USB Firewire	Bluetooth IEEE 802.12
Local Area (LAN)	Computers and communication equipment	Ethernet (IEEE 802.3) Frame Relay	IEEE 802.11
Metropolitan Area (MAN)	WAN access to local hosts	Local dial-up telephone ADSL Cable Modem T1/E1	WiMAX IEEE 802.16 IEEE 802.16 a - e
Wide Area (WAN)	Network access points	Internet backbone (IP router network) PSTN/PSDN (ESS and ATM networks)	HSCSD GPRS/EDGE cdma2000 data

The wMAN Niche

Broadband Wireless Access (BWA) at MAN level

High speed wireless access to networks at neighborhood level



802.16 Endpoints

Base Station (BS)

- Centrally located in neighborhoods
- Equivalent to
  - Base Station in cellular telephone network
  - WiFi access point
- Provides broadband service to Subscriber Stations

Subscriber Station (SS)

- Centrally located in buildings
- Equivalent to
  - Access router in a commercial building
  - ADSL modem with router/hub in home
- Provides
  - Aggregation/multiplexing for subscriber equipment
  - Subscriber access to broadband WAN

Advantages of wMAN

Replaces traditional microwave links
- Point-to-point digital trunk lines
- Used instead of high capacity digital cables / optical fibers

Expands public wLAN
- Covers neighborhood
- Provides access to global WAN

wLAN advantages on larger scale
- Quick service provision
- Serve hard-to-wire areas
- Avoid cable installation costs
- Avoid cable right-of-way problems
- Bring broadband to currently underserved area
- Simpler reconfiguration
- Mobility and roaming

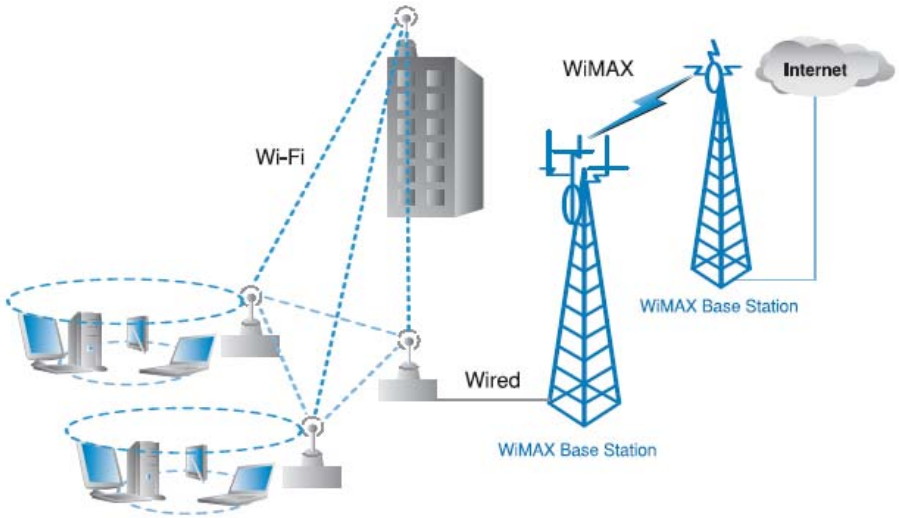
Marketing Prospects

Complement wired broadband access
- Compete with ADSL, cable modem, E1/T1 in advantageous markets
- Bring broadband access to underserved "last mile' markets
- Independent service providers may prefer alternative to Telco

WiFi creates demand for mobile broadband internet access
- Standard home and business wLANs based on IEEE 802.11
- WiMAX systems based on IEEE 802.16
- Hierarchy of complementary wireless mobile standards
  - IEEE 802.15 (Bluetooth) for Personal Area Network (wPAN)
  - IEEE 802.11 (WiFi) for Local Area Network (wLAN)
  - IEEE 802.16 (WiMAX) for Metropolitan Area Network (wMAN)

Profit centers
- High-revenue business customers
- High-volume residential subscribers

Wi-Fi / WiMAX Synergy



IEEE 802.16-2001

Target application
- Large businesses with high volume network traffic
- Communication service providers
  - ISPs and cellular providers
  - Alternative to Telco cables between service sites

10 to 66 GHz frequency range
- Line-of-sight (LOS) propagation
- Difficult requirements on transceiver position
  - Precise antenna alignment
  - Residential rooftops too low
  - Obstruction by trees and other buildings

Point-to-multipoint transmission
- Base Station to many Subscriber Stations

Provides very high digital capacity with full QoS

IEEE 802.16a-2003 — 802.16e-2005

Target application

- Residential applications
- Small/medium business (SMB)
- **MOBILE** access (802.16e)
- Basis for fixed and mobile WiMAX systems
  - Mobile WiMAX enables handoff of mobile SS from BS to BS
  - Handoff similar to other cellular sytems

2 to 11 GHz frequency range

- Non-line-of-sight (NLOS) operation
  - Transceivers may be placed on residential roofs
  - Antennas may be hidden for aesthetic reasons

Point-to-multipoint transmission

- Base Station to many Subscriber Stations

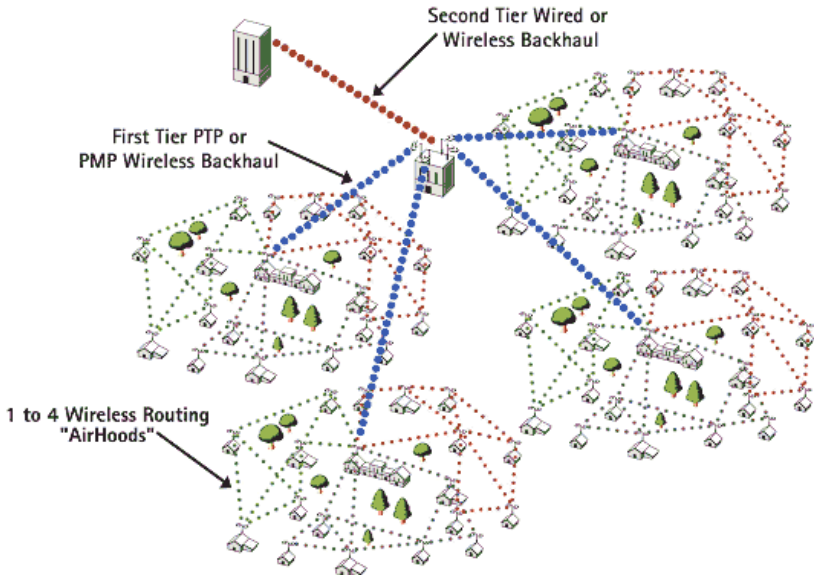
Lower digital capacity than IEEE 802.16

Provides full QoS

Frequency Ranges

Cellular telephony	**0.9 – 1.5 GHz**
802.11b (Wi-Fi)	**2.4 GHz**
802.11a	**5 GHz**
802.16a - e	**2 – 11 GHz**
802.16	**10 – 66 GHz**

Mesh Network in 802.16a



General Features of IEEE 802.16 Access

Standard of IEEE 802 committee

- Mandate limited to OSI layers 1 and 2
- Defines point-to-point infrastructure

Connection-oriented

- All services mapped to point-to-point connection (circuit mode)
  - Inherently connectionless services
  - Inherently connection-oriented services
- 16-bit Connection Identifier (CID) per connection
  - Defines transmission endpoints
- Connection established before data transmission

Access services

- Connect / disconnect
- Request bandwidth / grant bandwidth
- Negotiate QoS and traffic parameters
- Dynamic update of QoS parameters

802.16 Protocol Structure

MAC	Service Specific Convergence Sublayer (SSCS) Maps transport layers to MAC
	MAC Common Part Sublayer (MAC CPS) Access, frame structure, QoS
	Privacy Sublayer Authentication, key exchange, encryption
PHY	Transmission Convergence Sublayer (TCS)
	Physical Sublayer Modulation and channelization

TCS header	MAC header	MAC subheader (optional)	SSCS header	User data	CRC

Service Specific Convergence Sublayer

Well-defined interface to higher layer network services

- Classifies higher-layer PDUs
- Processes higher-layer PDUs based on classification

Payload Header Suppression (PHS)

- Registers PDU header information at connection set-up time
- Replaces PDU header with Connection Identifier (CID)

Service specific convergence sublayers

- ATM convergence sublayer (ATM CS)
  - Inherently connection-oriented service
- Packet convergence sublayer defined for (Packet CS)
  - Inherently connectionless service
  - IPv4 / IPv6
  - Ethernet
  - Point-to-point protocol (PPP)
  - Virtual local area network (VLAN)

Service Specific Convergence Sublayers

	Classification	Payload Header Suppression (PHS)
ATM	Virtual Path (VP) switched Virtual Channel (VC) switched	VPI and VCI connection descriptors mapped to 16-bit CID ATM circuit switching in WiMAX network handled by CID switching
Packet	Protocol type Priority	Remove repetitive headers MAC addresses IP addresses Original headers reconstructed when packets leave system

SSCS PDU

VP-switched ATM connection (VP mapped to CID)

Header				SSCS payload
PTI	CLP	Reserved	VCI	ATM cell payload (48 bytes)
3	1	4	16	

VC-switched ATM connection

VP/VC mapped to CID

Header			SSCS payload
PTI	CLP	Reserved	ATM cell payload (48 bytes)
3	1	4	

Packet-switched connection

Source / destination address pair mapped to CID

Header	SSCS payload
PHSI	IP or Ethernet PDU (header suppressed if PHSI = 1)
1	

MAC Connections

Standard 48-bit MAC address in subscriber station

- Identifies equipment for connection set-up

Following connection set-up

- 16-bit CID identifies SS-to-BS data flows

SS default connections

- Assigned automatically
- Used for SS-to-BS management operations

SS transport connections

- Requested / granted
- Managed dynamically
- Carry traffic for user services

Default Connections

Basic connection

- Used for short time-critical messages
  - MAC parameter management
  - Radio Link Control (RLC)

Primary management connection

- Used for longer delay-tolerant messages
  - Authentication
  - Connection setup

Secondary management connection

- Used for standards-based management messages
  - Dynamic Host Configuration Protocol (DHCP)
  - Trivial File Transfer Protocol (TFTP)
  - Simple Network Management Protocol (SNMP)

Transport Connections

Allocated for user services

- Each connection is unidirectional
  - Uplink or downlink
- Connections assigned to services in pairs
  - Uplink / downlink

Dedicated service connections

- SS contracts one connection per application / session
- Applications / sessions running in SS
- Applications / sessions running in clients connected to SS

Shared service connection

- One connection shared by several applications or sessions

MAC PDU

MAC Protocol Data Unit

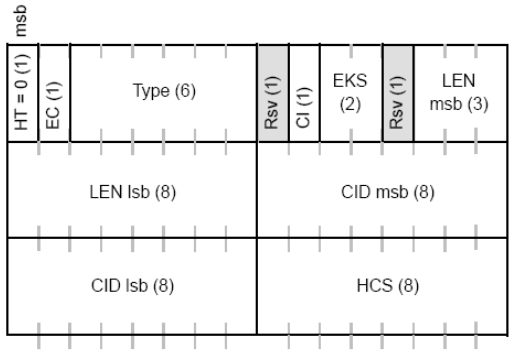
MAC header	MAC subheader (if present)	Payload (SSCS PDU)	CRC (if present)

MAC Header

- Fixed 48-bit header

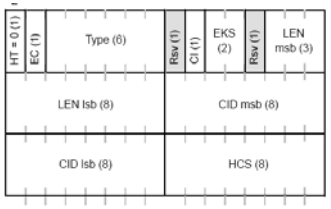
Two types

- Generic Header
  - HT = 0
- Bandwidth Request
  - HT = 1



Fields of Generic MAC Header

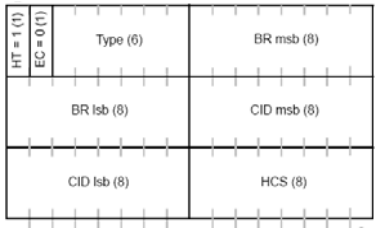
HT	1	0
EC	1	Encryption Control 0 = Payload is not encrypted 1 = Payload is encrypted
Type	6	Payload type with subheaders
CI	1	CRC Indicator 1 = CRC appended 0 = No CRC
EKS	2	Encryption Key Sequence Meaningful if EC = 1
LEN	11	Length (bytes) of PDU including header
CID	16	Connection Identifier
HCS	8	Header Check Sequence



Fields of Bandwidth Request MAC Header

Requests for uplink bandwidth (in bytes to send)

HT	1	1
EC	1	0
Type	6	"000000" for incremental requests "000001" for aggregate requests
BR	16	Bandwidth Request indicates number of bytes requested
CID	16	Connection Identifier indicates service flow for which uplink bandwidth is requested
HCS	8	Header Check Sequence



Grant Management Subheader

SS indicates bandwidth management needs to BS

PBR	PM	SI
2 bits	3 bits	3 bits

Piggy Back Request (PBR)

Number of bytes of uplink bandwidth requested by SS
Bandwidth request is for CID

Poll-Me (PM)

0 = No action
1 = Used by SS to request a bandwidth poll

Slip Indicator (SI)

0 = No action
1 = SS indicates a slip of uplink grants relative to uplink queue depth (risk of queue buffer overflow)

Fragmentation Subheader

Indicates presence of SDU fragments

FC	FSN	Reserved
2 bits	3 bits	3 bits

Fragmentation Control (FC)

Fragmentation state of payload
00 = no fragmentation
01 = last fragment
10 = first fragment
11 = continuing (middle) fragment

Fragmentation Sequence Number (FSN)

Defines sequence number of current SDU fragment
Increments by one (modulo 8) for each fragment

Packing Subheader

Indicates packing of multiple SDUs into single PDU

FC	FSN	Length
2 bits	3 bits	11 bits

MAC packs multiple SDUs into a single MAC PDU

Fragmentation Control (FC)

Fragmentation state of payload
00 = no fragmentation
01 = last fragment
10 = first fragment
11 = continuing (middle) fragment

Fragmentation Sequence Number (FSN)

Defines sequence number of current SDU fragment
Increments by one (modulo 8) for each fragment

Length

Length in bytes of SDU or SDU fragment
Includes two-byte packing subheader

MAC Link Management Messages

Downlink Channel Descriptor
Downlink Access Definition
Uplink Access Definition
Ranging Request / Response
Registration Request / Response
Privacy Key Management Request / Response
Dynamic Service Addition Request / Response / Acknowledge
Dynamic Service Change Request / Response / Acknowledge
Dynamic Service Deletion Request / Response
Multicast Assignment Request / Response
Downlink Burst Profile Change Request / Response
Reset Command
SS Basic Capability Request

Transmission Convergence Sublayer (TCS)

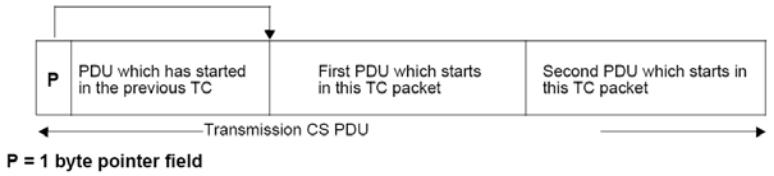
PHY accepts variable length MAC PDUs

TCS performs segmentation and reassembly (SAR)

Creates short fixed-length transmission blocks (like ATM)
FEC performed on fixed length data
Length depends on coding scheme
FEC block size 0 to 511 bytes
FEC payload 0 to 255 bytes

Pointer field prefixed to data field

Points to first byte in new MAC PDU



P = 1 byte pointer field

Physical Layer

	802.16	802.16-2004	802.16e-2005
Frequency bands	10 GHz – 66 GHz	2 GHz – 11 GHz	2 GHz – 11 GHz fixed 2 GHz – 6 GHz mobile
Propagation	Fixed LOS	Fixed NLOS	Fixed and mobile NLOS
Channels	20 – 28 MHz	1.75 - 8.75 MHz	
Transmission	Single carrier	Single carrier, 256 - 2,048 OFDM	
Data rate	32 – 134.4 Mbps	1 – 75 Mbps	
Multiplexing	Burst TDM / TDMA	Burst TDM / TDMA / OFDMA	
Topology	Point-to-multipoint + mesh		
Modulation	QPSK, 16 QAM, 64 QAM		
Duplexing	TDD and FDD		
WiMAX system	None	256 - OFDM as Fixed WiMAX	Scalable OFDMA as Mobile WiMAX

FEC Code Options

Reed-Solomon

- Useful either for large data blocks or high coding rates

Reed-Solomon + Block Convolutional Code

- Useful for low to moderate coding rates
- Provides good carrier-to-noise ratio (CNR)

Reed-Solomon + Parity check

- Useful for moderate to high coding rates with medium size blocks

Block Turbo Code

- Lowers required carrier-to-interference ratio (CIR) level
- Can be used to either
  - Extend range of a base station
  - Increase code rate for greater throughput

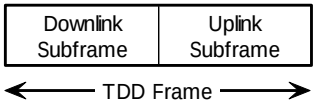
Channelization

802.16 frame

- Downlink subframe
  - BS broadcasts + BS time slots to each SS
- Uplink subframe
  - Time slots from each SS to BS

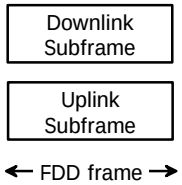
Time Division Duplexing (TDD)

- Subframes transmission
  - Alternate times
  - On same RF channel



Frequency Division Duplexing (FDD)

- Subframes transmission
  - Simultaneously
  - On separate RF channels
- Supports Half-Duplex (HD) FDD SSs
  - Simple devices cannot simultaneously send and receive



Time Slot Types

Time division multiplex (TDM)

- SS well-synchronized to BS
  - SS knows when to read its time slot
  - Similar to T1 / E1 multiplex
- Subframe content is MAC PDU
- Used for most downlink subframes

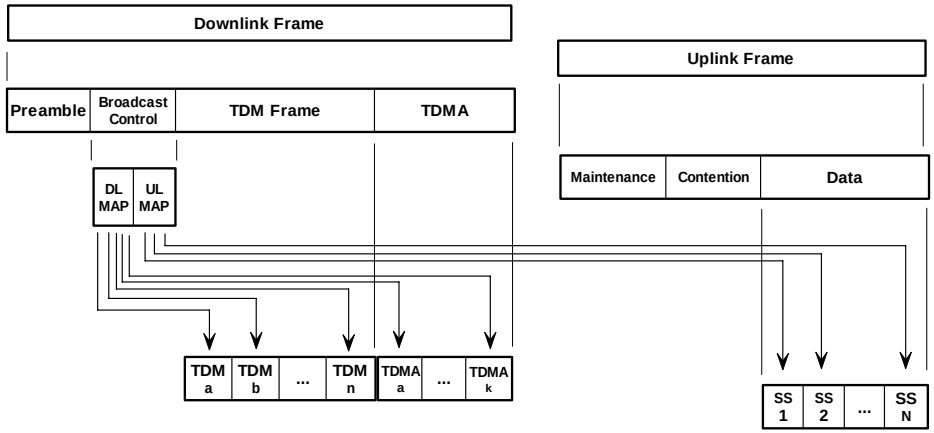
MAC header	Subheader	Data

Time division multiple access (TDMA)

- SS not well-synchronized to BS
  - Similar to Ethernet
- Synchronization preamble inserted before MAC PDU
- Used for all uplink subframes and HD-FDD downlink subframes

Preamble	MAC header	Subheader	Data

Frame Structure for FDD



TDMA time slots

DL / UL MAP Fields

DL MAP

- Contains table of Downlink Interval Usage Codes (DIUC)
- DIUC describes one transmission interval in DL data
  - A standard TDM interval or a TDMA interval

Downlink Interval Usage Code (DIUC)

- Transmission parameters used in transmit intervals
- Parameters: modulation, coding, symbol rate
- Usually respond to service requests by SS

UL MAP

- Uplink Interval Usage Codes (UIUC) grants uplink access to SS
- UIUC describes one transmission interval in UL data

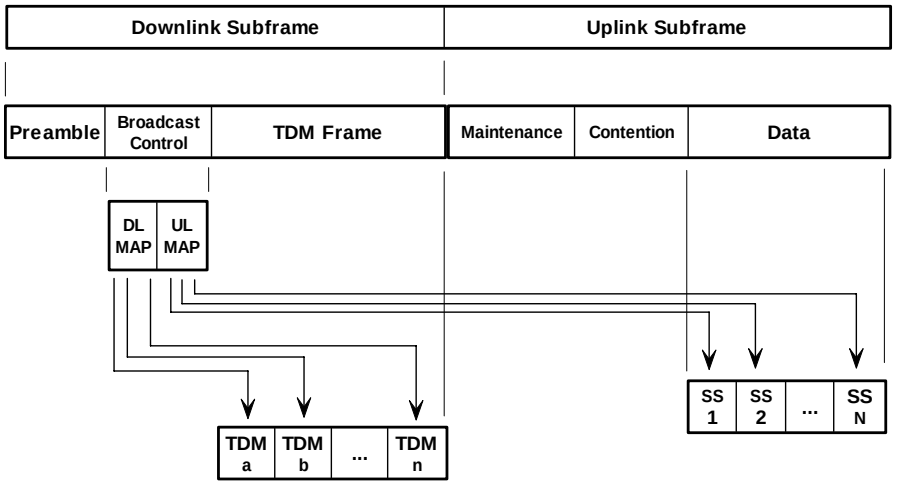
Uplink Interval Usage Code (UIUC)

- Transmission parameters used by SS in transmit intervals

Downlink TDMA Transmission Intervals

- BS transmits TDMA frames instead of TDM frames
- Used to support Half-Duplex devices

Frame Structure for TDD



Uplink Scheduling Services

Uplink connection mapped to scheduling service

Scheduling service

- Manages Request Grant Protocol between SS and BS
  - Allocates uplink capacity
- Enforces rules for BS scheduler
  - Rules negotiated at connection setup time

Scheduling types

- Unsolicited Grant Service (UGS)
- Polling Service
- Bandwidth Requests and Grants

Unsolicited Grant Service (UGS)

For services that periodically generate fixed units of data

- ATM constant bit rate (CBR)
- E1/T1

Scheduling determined at connection setup

- SS specifies requirements of underlying service
  - Bandwidth, delay and jitter
- Practical limit on jitter set by frame duration

Grants of negotiated size scheduled automatically by BS

- Grants scheduled at fixed time intervals
- No explicit request from SS
- Eliminates overhead and latency of bandwidth requests

Polling Service

Polling service

- Periodic dedicated request windows
- SS issues explicit requests
- Capacity granted according to real need of connection

Real-time polling service

- For connections carrying VoIP or streaming video/audio

Non-real-time polling service

- For Internet access with minimum guaranteed rate
- Longer delays and increased jitter

Bandwidth Requests / Grants

SS maintains multiple BS – SS connections

- Bandwidth granted for fixed transmission volume
- Initial bandwidth request followed by incremental requests

Grant Per SS (GPSS)

- Aggregate bandwidth allocated to SS
  - SS makes single request for aggregate bandwidth
  - BS grants aggregate bandwidth
- SS distributes granted bandwidth among connections / clients
- SS must manage bandwidth allocation among QoS requirements

Grant Per Connection (GPC)

- Bandwidth allocated per connection
  - SS requests / BS grants bandwidth per connection
- SS associates granted bandwidth among connections
- Uplink scheduling algorithm allocates QoS per connection / client
- Not permitted over 10 – 66 GHz PHY

Bandwidth Request Errors

Possible reasons for bandwidth request failure

- BS misses request due to PHY error or collision
- SS misses grant due to PHY errors
- BS did not have sufficient bandwidth available
- GPSS SS allocated bandwidth to wrong purpose

Self-correcting protocol

- After timeout appropriate for QoS of connection
- SS repeats requests

Channel Acquisition

Automatic initialization procedure

On SS activation

- SS scans frequency list for operating channel
- Detects periodic frame preambles
- Synchronizes to downlink transmission

Synchronized SS

- Looks for broadcast messages
  - Downlink Channel Descriptor (DCD)
  - Uplink Channel Descriptor (UCD)
- SS learns modulation and FEC schemes

Initial Negotiation of Capabilities

SS looks for initial ranging opportunities

- Ranging = initial transmissions for testing
- Scans UL-MAP messages present in every frame

SS makes initial ranging transmissions

- Uses most robust least efficient burst profile
- Reports its PHY capabilities
  - Modulation and coding schemes
  - Half-duplex or full-duplex (in FDD)

BS grants or denies SS capabilities

Authentication and Registration

SS maintains

- X.509 digital certificate
- Manufacturer certificate
- Establish link between 48-bit MAC address public RSA key

SS sends certificates to BS

- Authorization Request message
- Authentication Information message

Network verifies identity of SS

- Checks certificates
- Checks level of authorization of SS

If SS is authorized to join network

- BS responds to request with Authorization Reply
- Contains Authorization Key (AK) encrypted with SS public key

SS registers with network

- Establish secondary management connection
- Determine capabilities for connection setup and MAC operation

IP Connectivity

After registration

- SS obtains IP address via DHCP
- Establishes time of day via internet Network Time Protocol (NTP)

DHCP server provides address of TFTP server

- SS requests configuration file from TFTP server
  - TFTP = Trivial File Transfer Protocol
- Configuration file
  - Vendor-specific configuration information

Connection Setup

Service Flows

- Define unidirectional transport of packets on downlink or uplink
- Characterized by QoS parameters
  - Bandwidth, latency, and jitter
- Mapped to a MAC connection with a unique CID
- Usually initiated by BS during SS initialization
- Can be dynamically established by either BS or SS
  - For dynamically signaled connection such as ATM SVC

Service flow establishment via three-way handshaking protocol

- Request for service flow
- Response
- Acknowledged

Radio Link Control

Burst Profile

- Collections of defined transmission parameters
  - Power control and ranging
  - Modulation and encoding

Currently defined uplink and downlink burst profiles

- BS periodically broadcasts list of profiles
- Profiles identified by
  - Uplink Interval Usage Code (UIUC)
  - Downlink Interval Usage Code (DIUC)
- SS can request temporary switch from one burst profile to another
- Depends on weather and equipment capabilities

RLC provides controls capability via MAC layer

- UL and DL burst profiles for SS

Requesting Change in Downlink Burst Profile

- BS allocates maintenance interval to SS
- SS uses Ranging request message
- Requests change in downlink burst profile
- SS transmits downlink burst profile change request
- BS responds with confirmation or denial of change